Real-Time Strong Motion Response Spectra Determination in Support of Rapid Damage Assessment from Large Earthquakes

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Traditional Strong Motion Response Spectra Determinations

- Event detection and recording at remote dataloggers
- After complete recording, event files are telemetered back to data processing center
- Strong motion response spectra are then computed over the entire event recording
- Latency for producing final results are in the 10s of seconds to minutes range mainly depending on the latencies in assimilating event files in the dataloggers

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New Strong Motion Response Spectra Determination

- We present the results of computing strong motion response spectra based upon a new software processing system, **`Bighorn`**
- **`Bighorn`** does not depend on event detection by the dataloggers
- Rather it processes real-time accelerogram data streams and produces real-time strong motion response spectra to produce damage estimates as soon as possible
- Although the results show here are for single stations, all of the software has been fully threaded on a per station basis so that similar results can be obtained over multiple stations on computer hosts with multiple independent hyper-threads.

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Strong Motion Response Spectra Equations of Motion

- Strong Motion Response Spectra defined as a set of maximum amplitude values from a comb of damped harmonic oscillators

The basic SMR EOMs can be expressed as a Laplace transfer function,

$$\mathrm{H}(S) = \frac{\omega^2 + 2\xi\omega S}{\omega^2 + 2\xi\omega S + S^2}$$

Where ω = oscillator natural frequency in radians per second
and ξ = oscillator damping ratio

- This transfer function can be designed using normal digital filtering methodologies. The resulting recursion relation requires 5 multiplies per sample per oscillator as opposed to the 10 multiplies per sample per oscillator required in the traditional numerical integration based approach.

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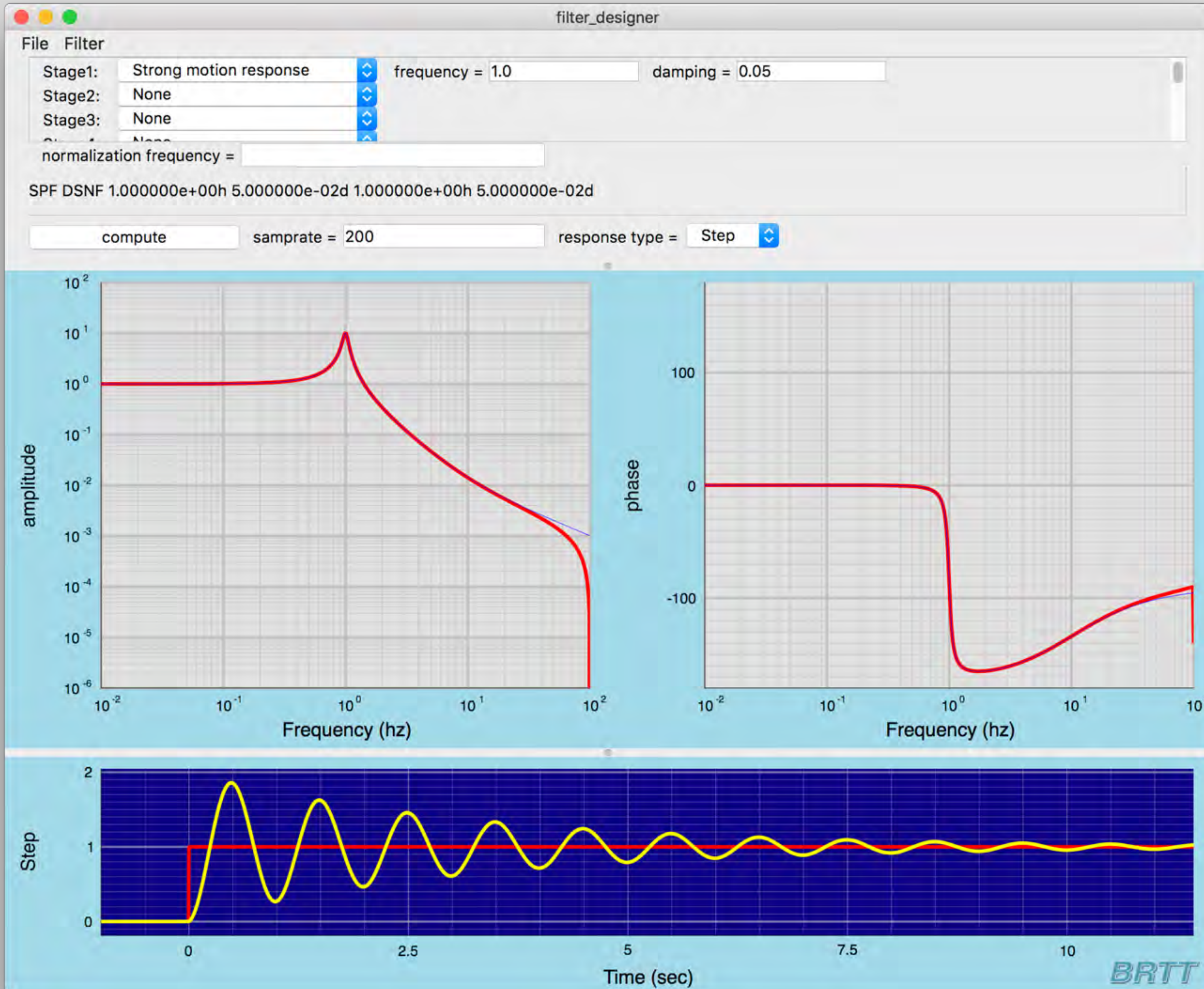
filter_designer
File Filter
Stage1: Strong motion response
frequency = 1.0
damping = 0.05
Stage2: None
Stage3: None
normalization frequency =
SPF DSNF 1.000000e+00h 5.000000e-02d 1.000000e+00h 5.000000e-02d
compute
samprate = 200
response type = Step
amplitude
Frequency (hz)
phase
Frequency (hz)
Step
Time (sec)
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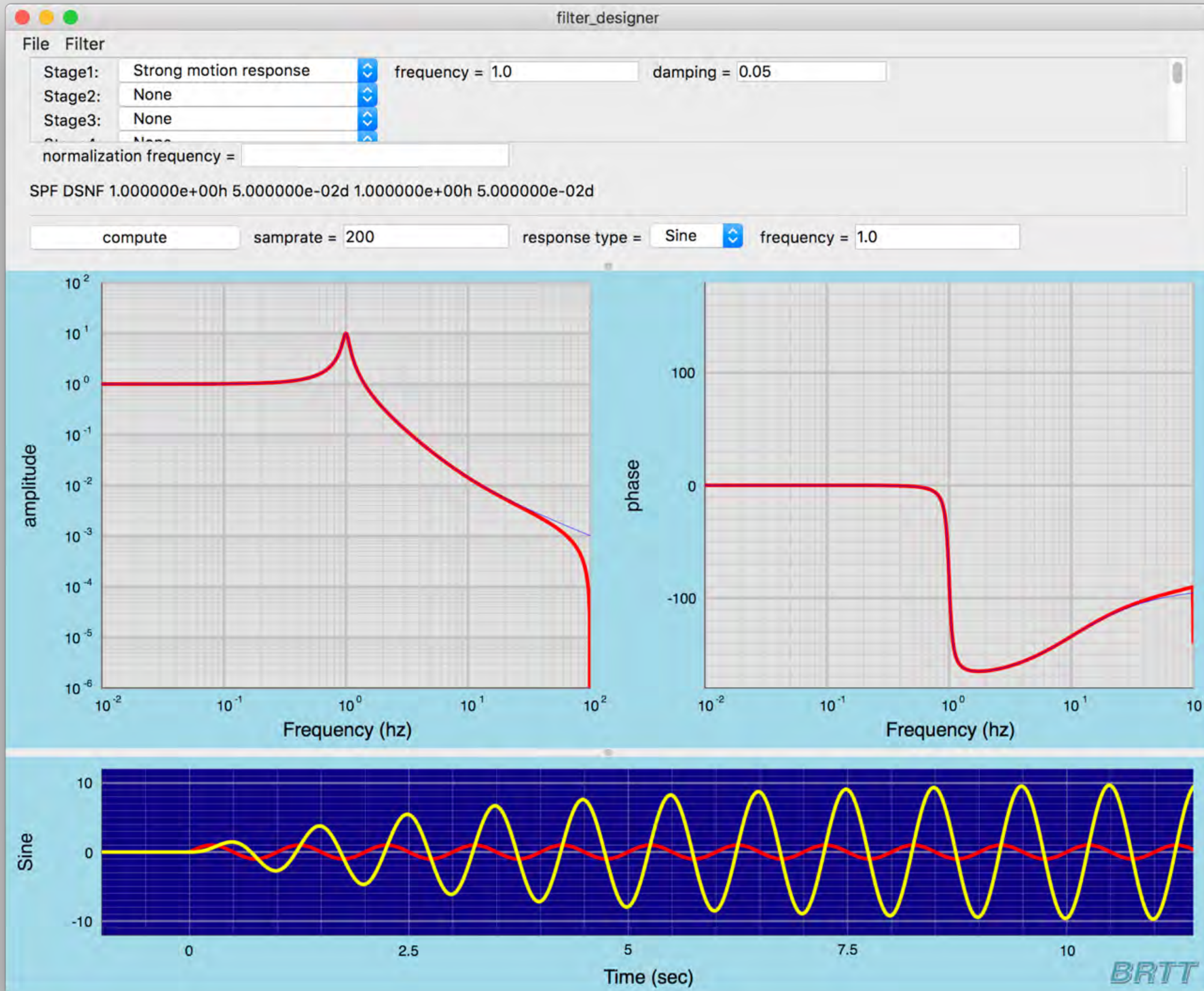
filter_designer
File Filter
Stage1: Strong motion response
frequency = 1.0
damping = 0.05
Stage2: None
Stage3: None
normalization frequency =
SPF DSNF 1.000000e+00h 5.000000e-02d 1.000000e+00h 5.000000e-02d
compute
samprate = 200
response type = Sine
frequency = 1.0
amplitude
Frequency (hz)
phase
Frequency (hz)
Sine
Time (sec)
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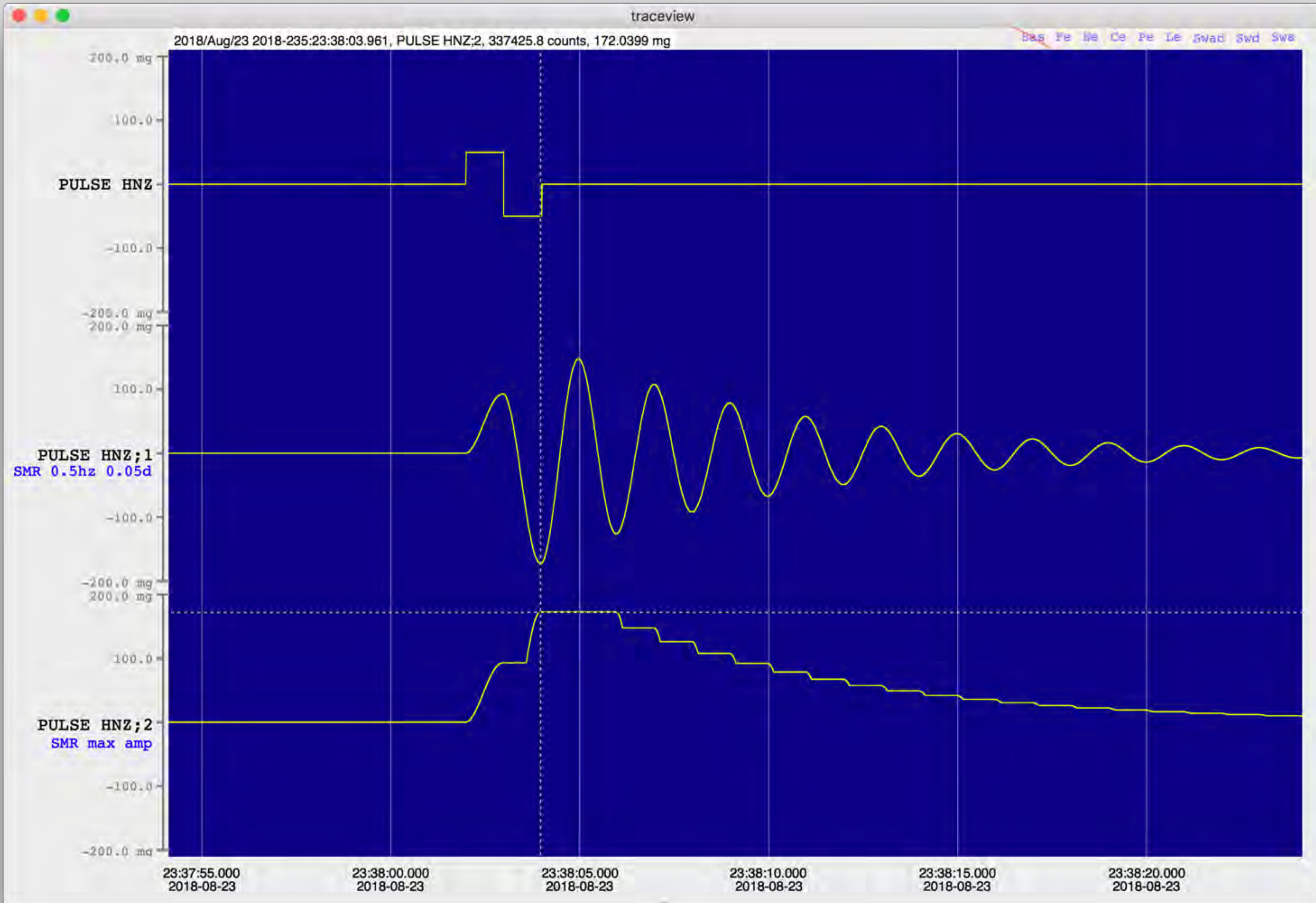
traceview
2018/Aug/23 2018-235:23:38:03.961, PULSE HNZ;2, 337425.8 counts, 172.0399 mg
PULSE HNZ
PULSE HNZ;1
SMR 0.5hz 0.05d
PULSE HNZ;2
SMR max amp
200.0 mg
100.0
-100.0
-200.0 mg
23:37:55.000 2018-08-23
23:38:00.000 2018-08-23
23:38:05.000 2018-08-23
23:38:10.000 2018-08-23
23:38:15.000 2018-08-23
23:38:20.000 2018-08-23

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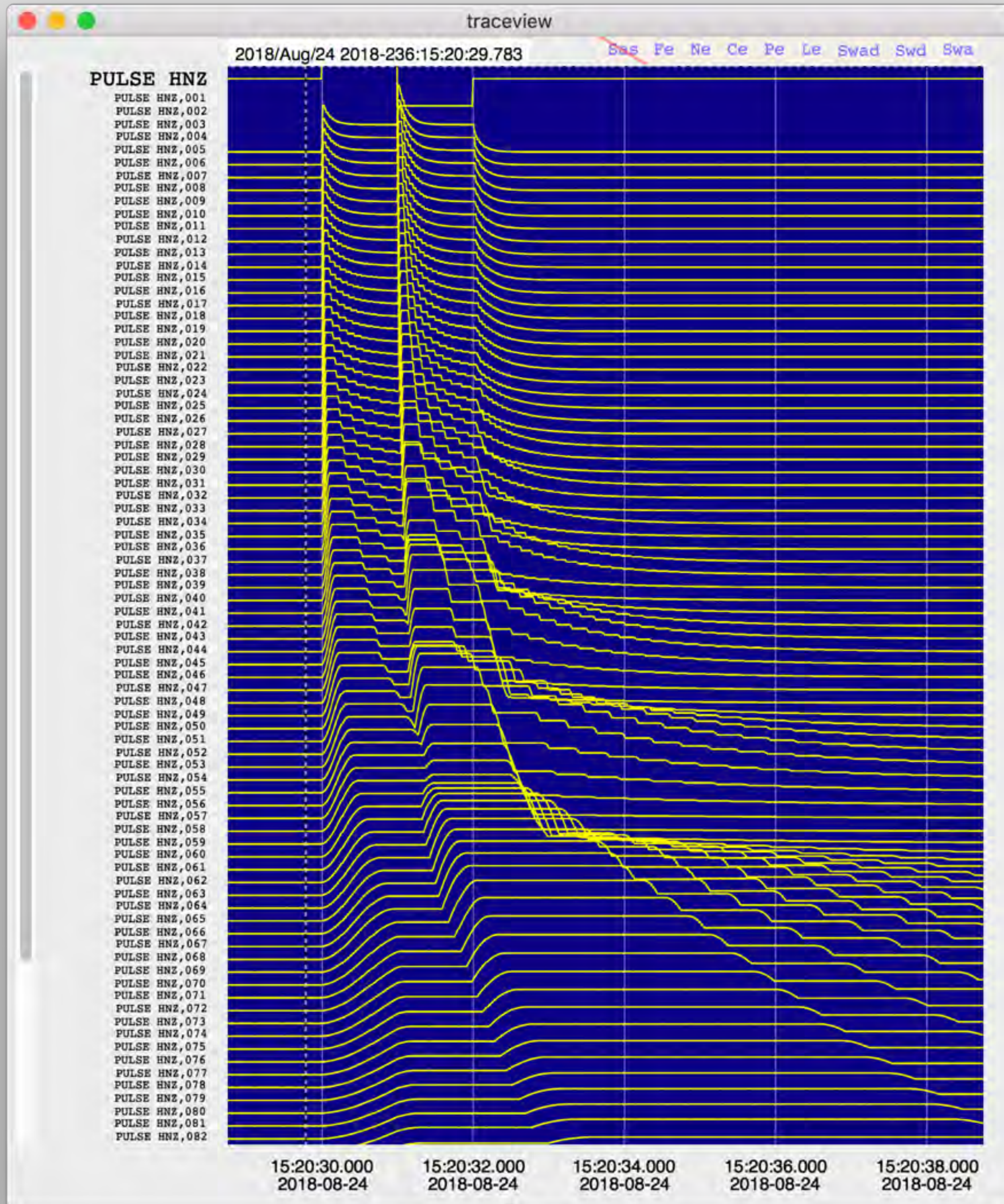
traceview
2018/Aug/24 2018-236:15:20:29.783
Sas Fe Ne Ce Pe Le Swad Swd Swa
PULSE HNZ
PULSE HNZ,001
PULSE HNZ,002
PULSE HNZ,003
PULSE HNZ,004
PULSE HNZ,005
PULSE HNZ,006
PULSE HNZ,007
PULSE HNZ,008
PULSE HNZ,009
PULSE HNZ,010
PULSE HNZ,011
PULSE HNZ,012
PULSE HNZ,013
PULSE HNZ,014
PULSE HNZ,015
PULSE HNZ,016
PULSE HNZ,017
PULSE HNZ,018
PULSE HNZ,019
PULSE HNZ,020
PULSE HNZ,021
PULSE HNZ,022
PULSE HNZ,023
PULSE HNZ,024
PULSE HNZ,025
PULSE HNZ,026
PULSE HNZ,027
PULSE HNZ,028
PULSE HNZ,029
PULSE HNZ,030
PULSE HNZ,031
PULSE HNZ,032
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PULSE HNZ,067
PULSE HNZ,068
PULSE HNZ,069
PULSE HNZ,070
PULSE HNZ,071
PULSE HNZ,072
PULSE HNZ,073
PULSE HNZ,074
PULSE HNZ,075
PULSE HNZ,076
PULSE HNZ,077
PULSE HNZ,078
PULSE HNZ,079
PULSE HNZ,080
PULSE HNZ,081
PULSE HNZ,082
15:20:30.000
2018-08-24
15:20:32.000
2018-08-24
15:20:34.000
2018-08-24
15:20:36.000
2018-08-24
15:20:38.000
2018-08-24

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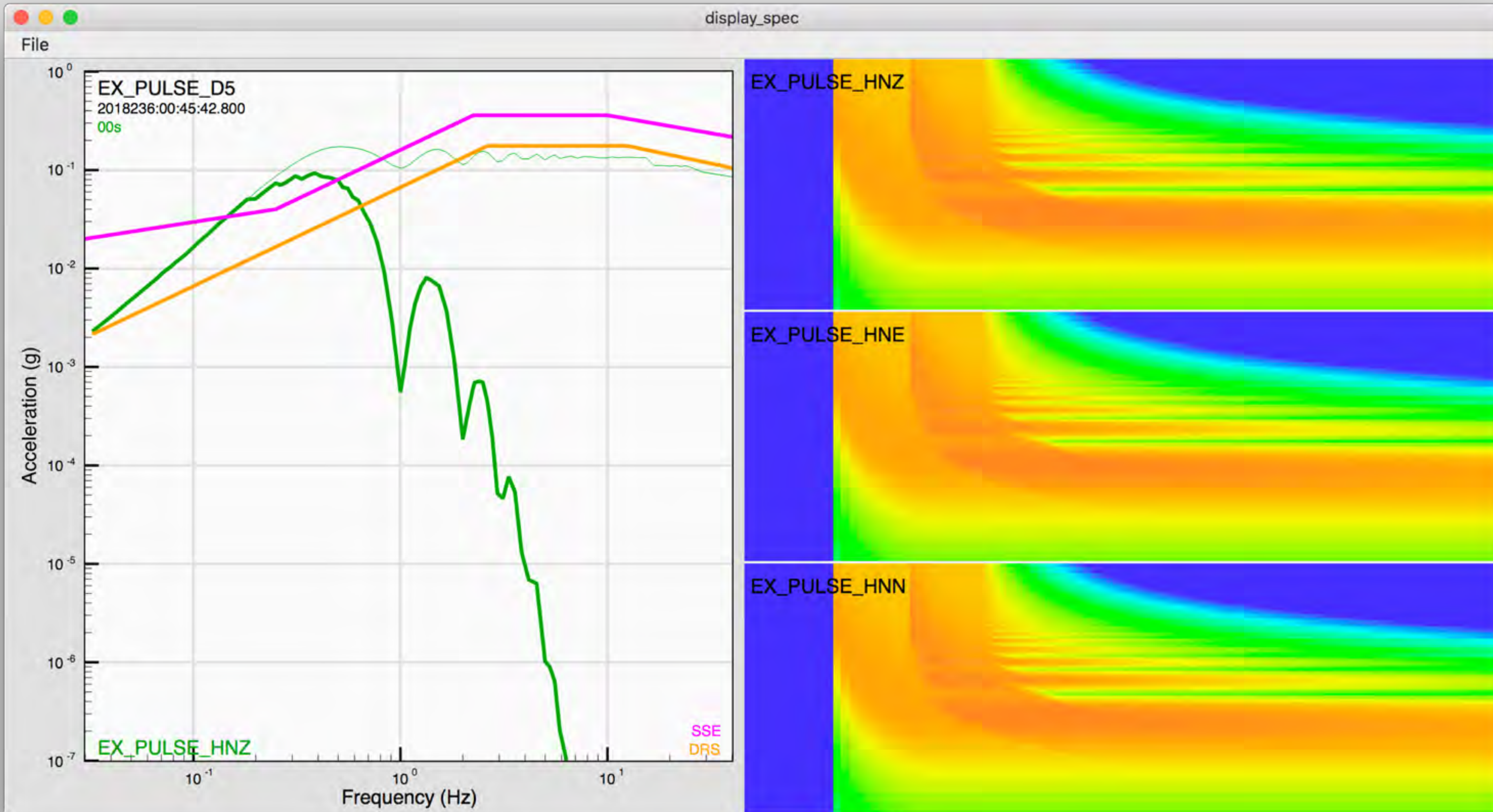
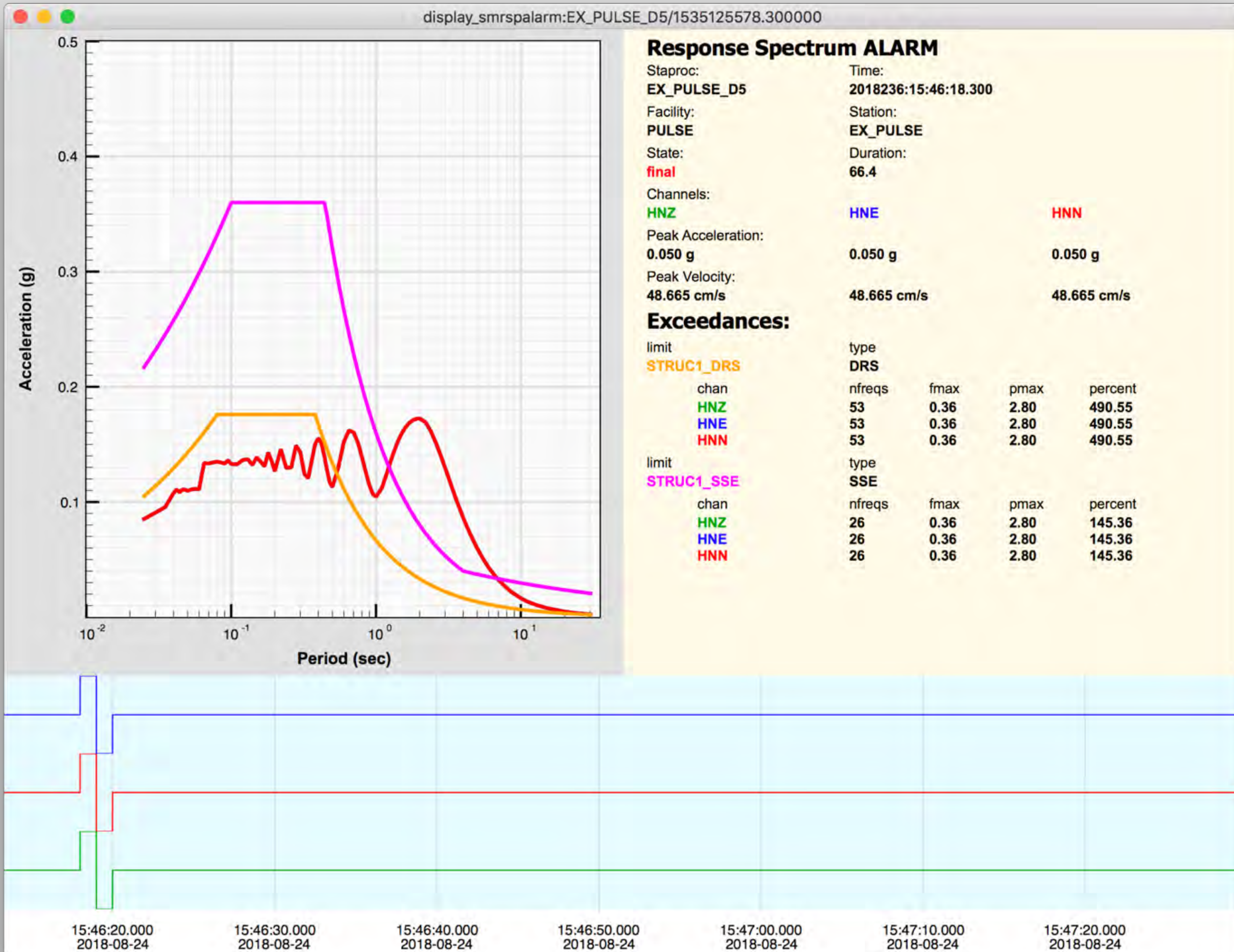


display_spec
File
EX_PULSE_D5
2018236:00:45:42.800
00s
EX_PULSE_HNZ
SSE
DRS
Acceleration (g)
Frequency (Hz)
EX_PULSE_HNZ
EX_PULSE_HNE
EX_PULSE_HNN


display_smrspalarm:EX_PULSE_D5/1535125578.300000
Acceleration (g)
Period (sec)
Response Spectrum ALARM
Staproc:
EX_PULSE_D5
Time:
2018236:15:46:18.300
Facility:
PULSE
Station:
EX_PULSE
State:
final
Duration:
66.4
Channels:
HNZ HNE HNN
Peak Acceleration:
0.050 g 0.050 g 0.050 g
Peak Velocity:
48.665 cm/s 48.665 cm/s 48.665 cm/s
Exceedances:
limit type
STRUC1_DRS DRS
chan nfreqs fmax pmax percent
HNZ 53 0.36 2.80 490.55
HNE 53 0.36 2.80 490.55
HNN 53 0.36 2.80 490.55
limit type
STRUC1_SSE SSE
chan nfreqs fmax pmax percent
HNZ 26 0.36 2.80 145.36
HNE 26 0.36 2.80 145.36
HNN 26 0.36 2.80 145.36
15:46:20.000 2018-08-24
15:46:30.000 2018-08-24
15:46:40.000 2018-08-24
15:46:50.000 2018-08-24
15:47:00.000 2018-08-24
15:47:10.000 2018-08-24
15:47:20.000 2018-08-24

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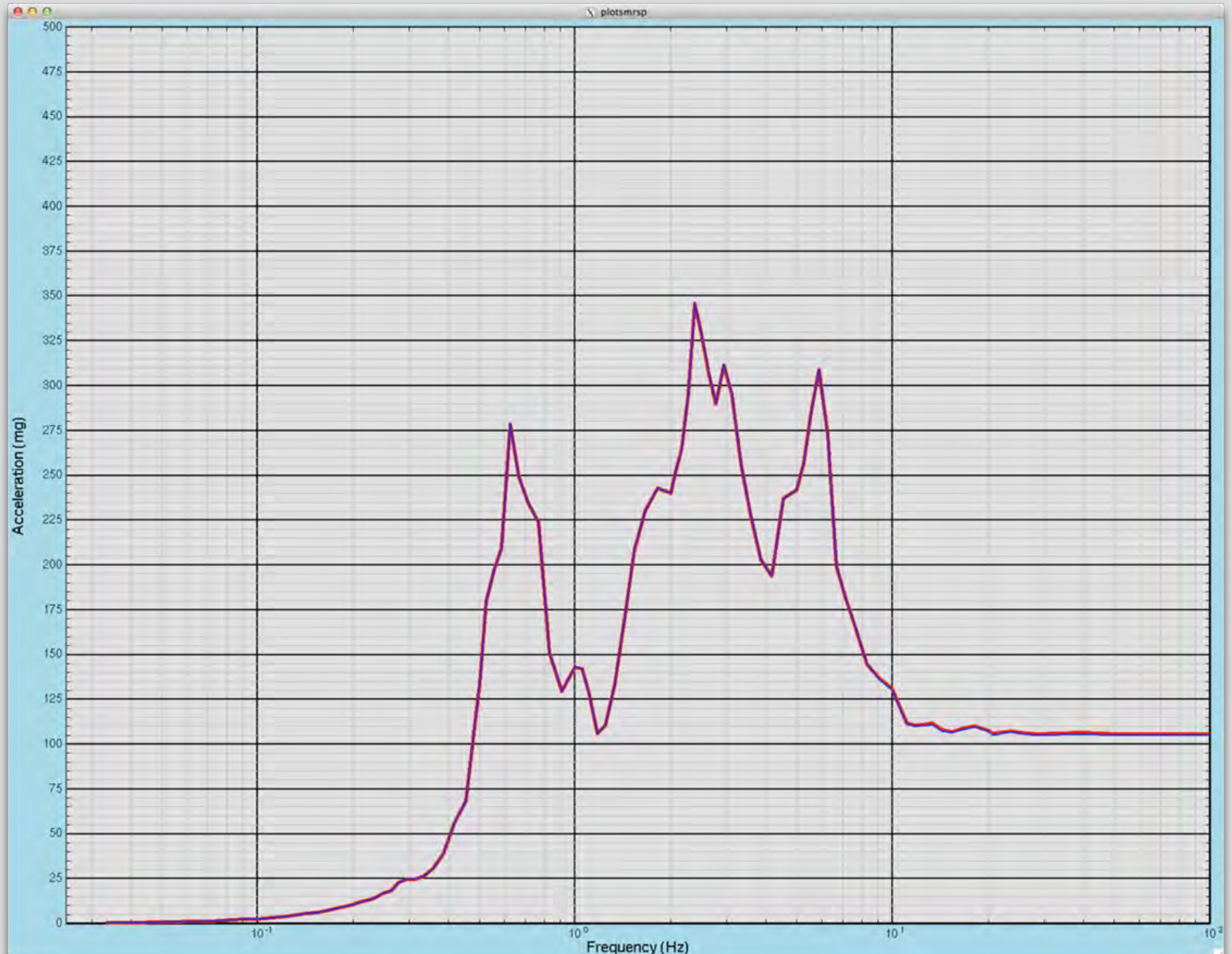

plotsmrsp
Acceleration (mg)
Frequency (Hz)
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
10^{-1}
10^{0}
10^{1}
10^{2}

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Latencies

- We present the results of computing time latencies strong motion response spectra produced by **`Bighorn`**
- All processing was done on a single 3-component station over the 96 oscillators shown previously
- Latencies were computed by subtracting the data time stamps from the system time. All of these results were generated on an Apple laptop computer with the system time synchronized using NTP.
- Both simulation results using the same test signal as used previously and real data from a remote datalogger will be shown

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display_smrsplatency
Data 7.25
SMR 20.97
SMR-Data 13.72
Latency (msec)
100
90
80
70
60
50
40
30
20
10
0
12:30:00.000 2018-08-23
12:45:00.000 2018-08-23
13:00:00.000 2018-08-23
13:15:00.000 2018-08-23
13:30:00.000 2018-08-23
13:45:00.000 2018-08-23
14:00:00.000 2018-08-23
14:15:00.000 2018-08-23
Time

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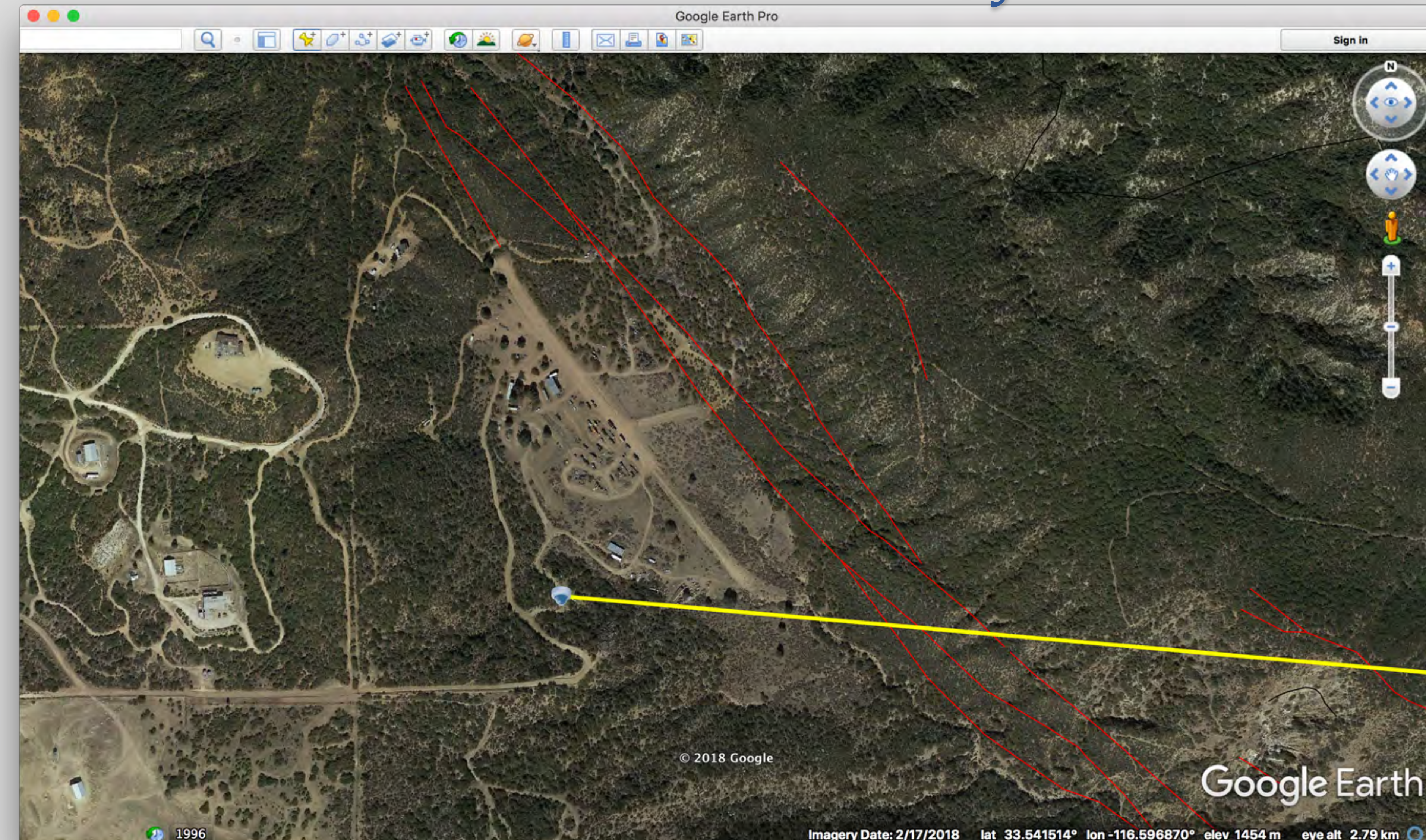
Sagebrush Flats – Etna 2
300 meters from SJF



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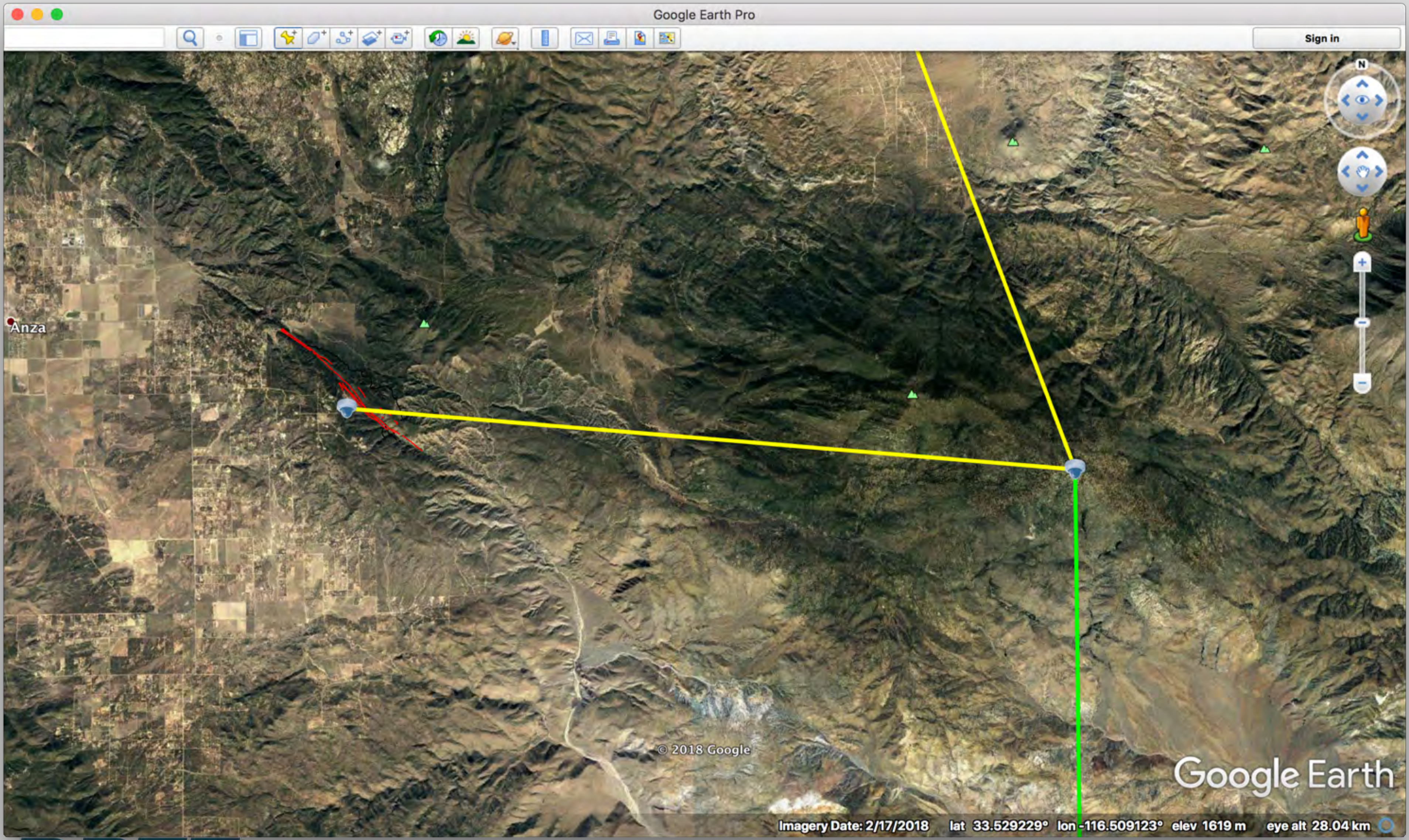
Sagebrush Flats to Toro Peak
15.5 km link



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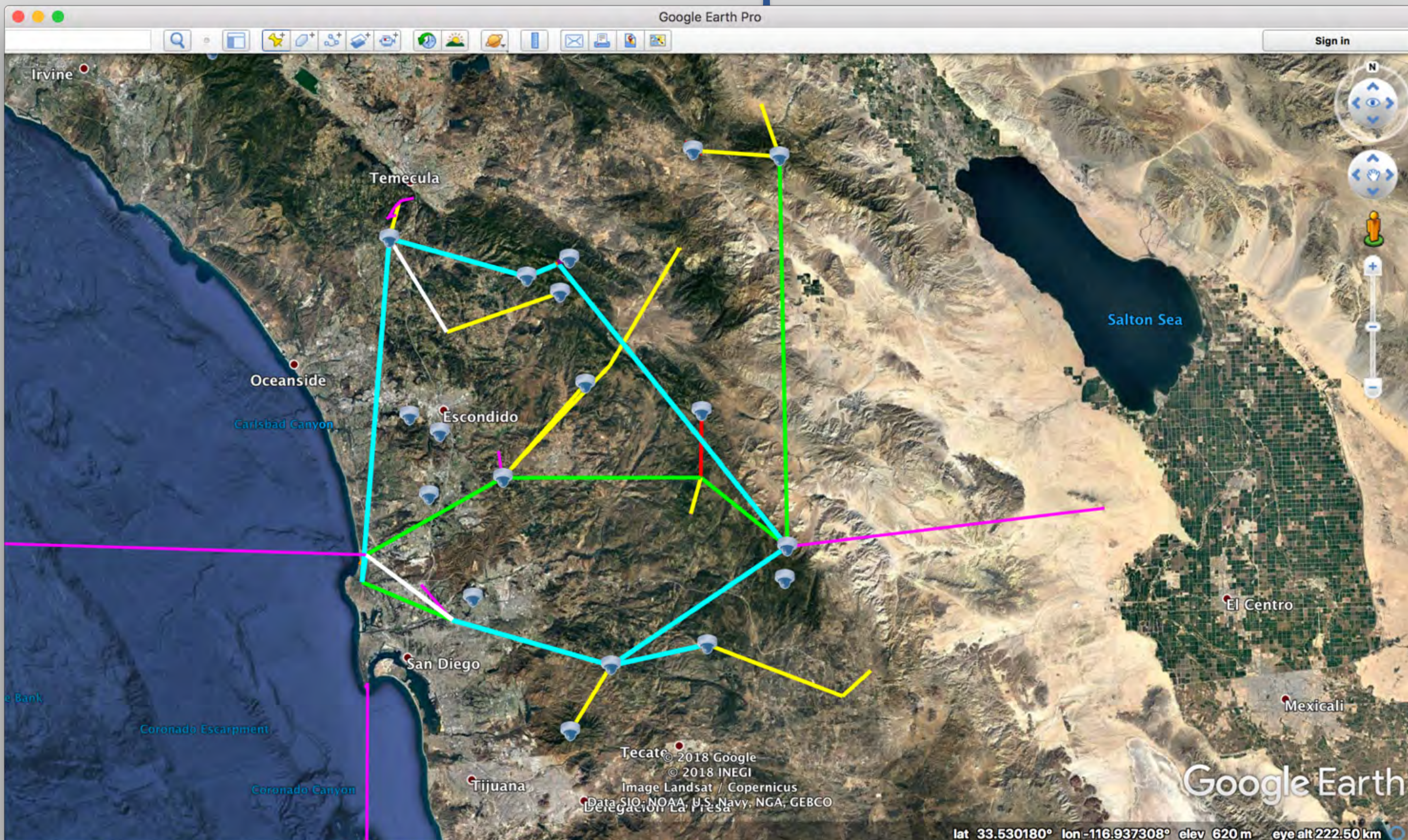
Sagebrush Flats – UCSD
5 Hops



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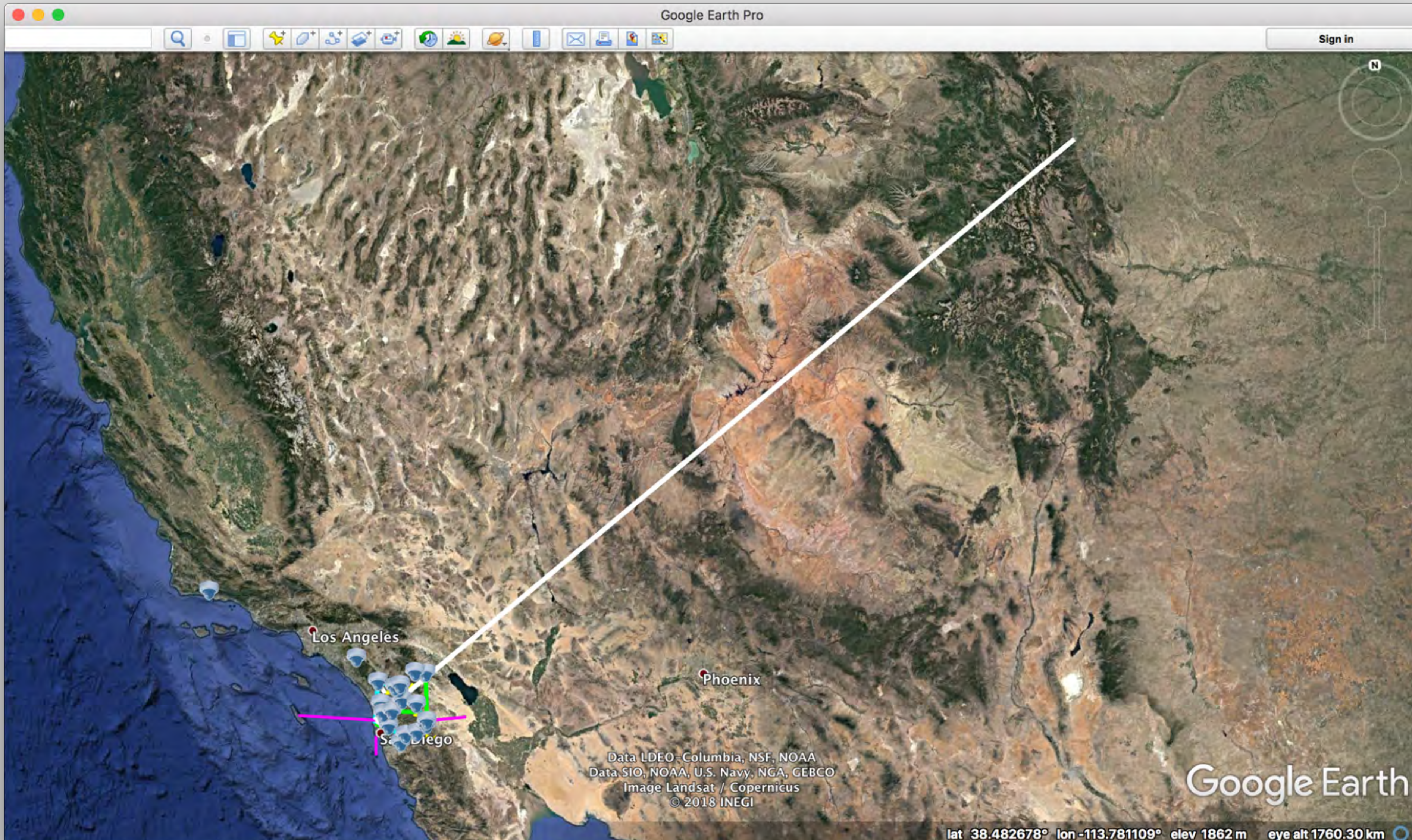
Sagebrush Flats – Boulder Public Domain Internet



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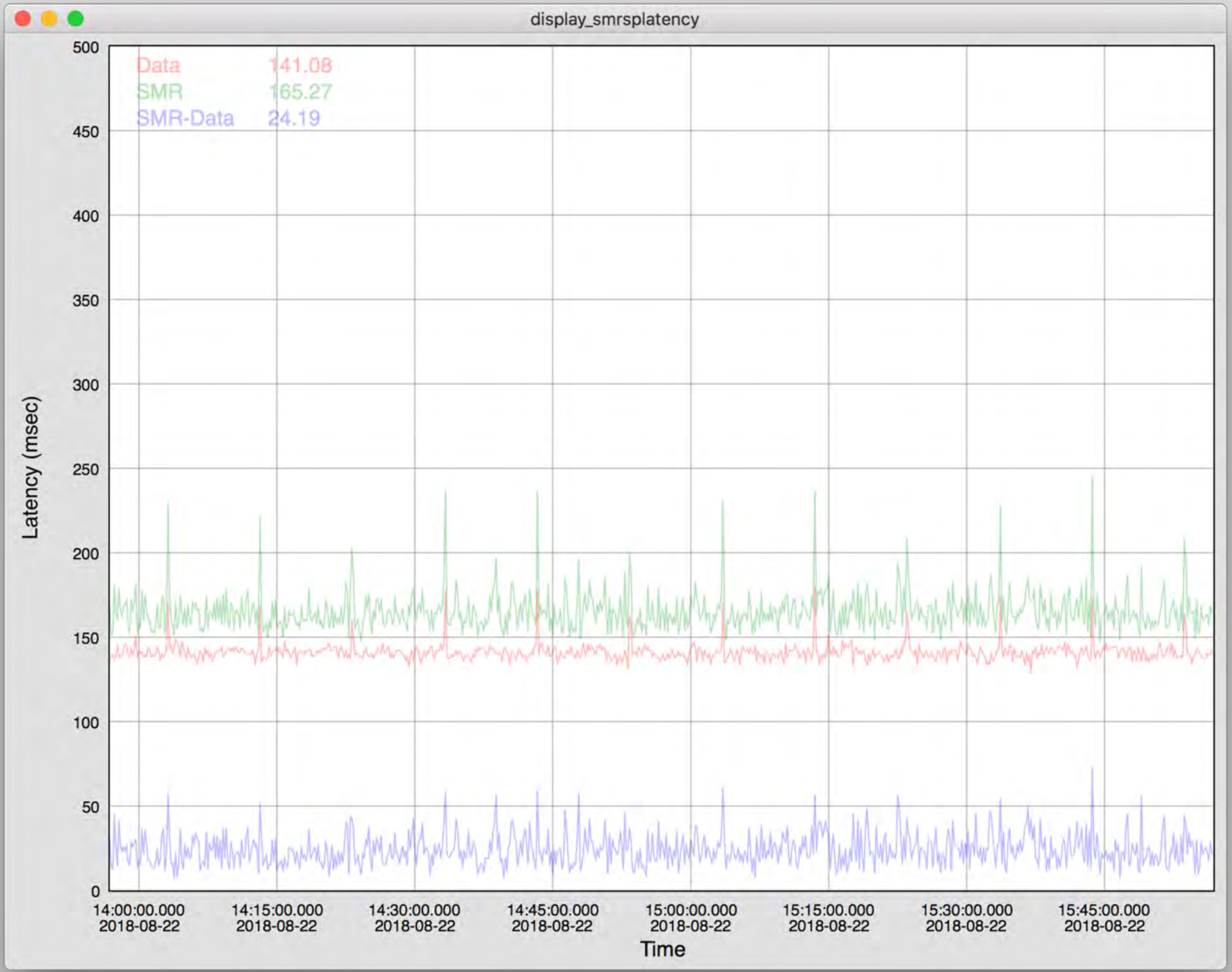
display_smrsplatency
Data 141.08
SMR 165.27
SMR-Data 24.19
Latency (msec)
500
450
400
350
300
250
200
150
100
50
0
14:00:00.000 2018-08-22
14:15:00.000 2018-08-22
14:30:00.000 2018-08-22
14:45:00.000 2018-08-22
15:00:00.000 2018-08-22
15:15:00.000 2018-08-22
15:30:00.000 2018-08-22
15:45:00.000 2018-08-22
Time

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Conclusions

- `Bighorn` produces real-time strong motion response spectra efficiently with processing latencies of approximately 25 msec.
- With proper data sources, these results can be compared in real time against exceedance levels to produce potential structure damage alarms within fractions of one second
- `Bighorn` greatly reduces damage alarm latencies relative to traditional strong motion response processing systems

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